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Project Director: P. H. Wright

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Grant/Contract Closeout Actions Remaining:

- _ Final Invoice and Closing Documents
- _ Final Fiscal Report
- _ Final Report of Inventions
- _ Govt. Property Inventory & Related Certificate
- _ Classified Material Certificate
- _ Other ____________

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CA-4 (1/79)

AMELIORATION OF ROADSIDE OBSTACLE CRASHES

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AMELIORATION OF ROADSIDE OBSTACLE CRASHES

Researchers have found that a roadway's crash experience is associated with its geometric design and roadside features. Inadequacies in roadway design tend to be especially significant in crashes involving a vehicle which leaves the travelled way and strikes a fixed object.

Pennsylvania has reported that 40 percent of all fatal crashes in that state are the result of hitting a fixed object such as a tree, utility pole, or bridge abutment (1). Fixed object collisions account for 31 percent of all fatal highway crashes and 20 percent of all highway crashes in Maryland (1). Clearly, collisions with unyielding obstacles along the roadside remain a serious and as yet largely uncorrected problem.

In view of the enormity of the task of fixing all unsafe highway conditions, highway engineers, faced with limited funds, should select those sections for safety improvements which will yield the greatest benefits. This implies a need for a sound, rational basis for the selection of the most beneficial roadway safety projects. In recognition of this need, a study (2) was undertaken at Georgia Institute of Technology in 1974 with the goal of developing priorities for the improvement of roadway geometric features and roadsides for safety.

In the 1974 study, roadway surveys and inventories of roadside obstacles were made at 300 sites of fatal fixed object crashes in Georgia and at 300 comparison sites 1.6 kilometers (1 mile) away on the road that the vehicle likely had travelled. Since that study was confined to fatal crashes, it left open the question of whether the priority strategy recommended would ameliorate a larger set of crashes, i.e., those of all levels of severity. The research reported herein, which focused on personal injury and property damage only crashes as well as fatal crashes, was designed to determine if the priority modification scheme developed earlier would be appropriate for the amelioration of non-fatal as well as fatal fixed object crashes.

METHODOLOGY

Except for the type of crashes studied and the sampling procedure, the methodology used for this study was identical to that employed in the earlier study (2). The study was designed to identify roadway characteristics at sites where a vehicle struck one or more roadside objects compared with roadway characteristics at sites one mile upstream from the crash site. Differences between the sites can be used to identify sites where roadside obstacle crashes are more likely to occur, since the exposure to both the crash and comparison sites can be considered to be approximately equal. Comparison of characteristics of these case and comparison sites with available data on characteristics of roadways in the area studied provides additional criteria for selecting sites for modification.

The study area was confined to three counties in North Georgia: Fulton, Cobb, and Bartow. The sampling for Fulton County was confined to those crashes which occurred within the city limits of Atlanta. Cobb County is a suburban county which lies contiguous to and northwest of Fulton County, while Bartow County is situated farther to the northwest in a rural setting. The study area includes a variety of land uses, roadway types, and topography.

Police accident reports were randomly selected from the files of eight police jurisdictions in the three counties. Overturning cases, those not involving significant impact with an object, were excluded. Cases in which an object had not been struck were eliminated by review of the police report or in certain cases, by a visit to the crash site. Seven cases were replaced because researchers were unable to locate the crash site due to inadequate or erroneous information in the accident report or lack of physical evidence in the accident vicinity. Four cases were replaced because the comparison site was non-existent (e.g., in a parking lot or on a cul-de-sac), and three cases were not used because the sites were on private property.

The crashes studied occurred during a five-month period beginning September 1, 1977. The sampling scheme employed is shown in Table 1. It produced a sample which closely represents the statewide fixed-object crash population, as Table 2 demonstrates.

Engineering surveys were made, usually by three-person teams, at 300 crash locations and 300 comparison locations. The surveys were confined to a 0.32 kilometer (0.2 mile) section at each of the locations. The measurements were referenced to the object which likely took the greatest impact. A point along the roadway edge immediately adjacent to the selected object was identified as the "crash site". As Figure 1 illustrates, a point one mile upstream from the crash site was designated as the "comparison site". When locating the comparison sites, choice of turns at T- or Y- intersections were made randomly (by flip of a coin).

Measurements of curvature and superelevation were made beginning 15.2 meters (50 feet) from the site and at 30.5 meter (100 foot) intervals for 137.2 meters (450 feet) both upstream and downstream, respectively, of the crash site and the comparison site. The gradient was measured at every 30.5 meters (100 feet) for 152.4 meters (500 feet) both upstream and downstream of the reference sites.

Simple measuring instruments that involved a minimum amount of time at the survey locations were used. A 30.5 meter (100-foot) cloth tape was used for measuring distances. Horizontal curvatures were measured by the middle ordinate method previously employed (3). The curve measurements were usually

Table 1. Sampling scheme and fixed object crash statistics for study area.

Jurisdiction	Sample Fraction	Fixed-Object Crash Statistics, 1976 Fatal	Non-Fatal Injury	Property Damage	Total
Atlanta	1 in 20(5%)	9	822	1,587	2,418
Cobb County	1 in 3(33%)	8	192	422	622
Bartow County	1 in 1(100%)	1	46	64	111

Table 2. Sample Crashes, by severity, compared to statewide crashes.

Area	Fatal	Non-Fatal Injury	Property Damage	Total
Georgia	135	4,354	8,300	12,789
	1%	34%	65%	100%
Survey Area	7	112	181	300
	2%	37%	61%	100%

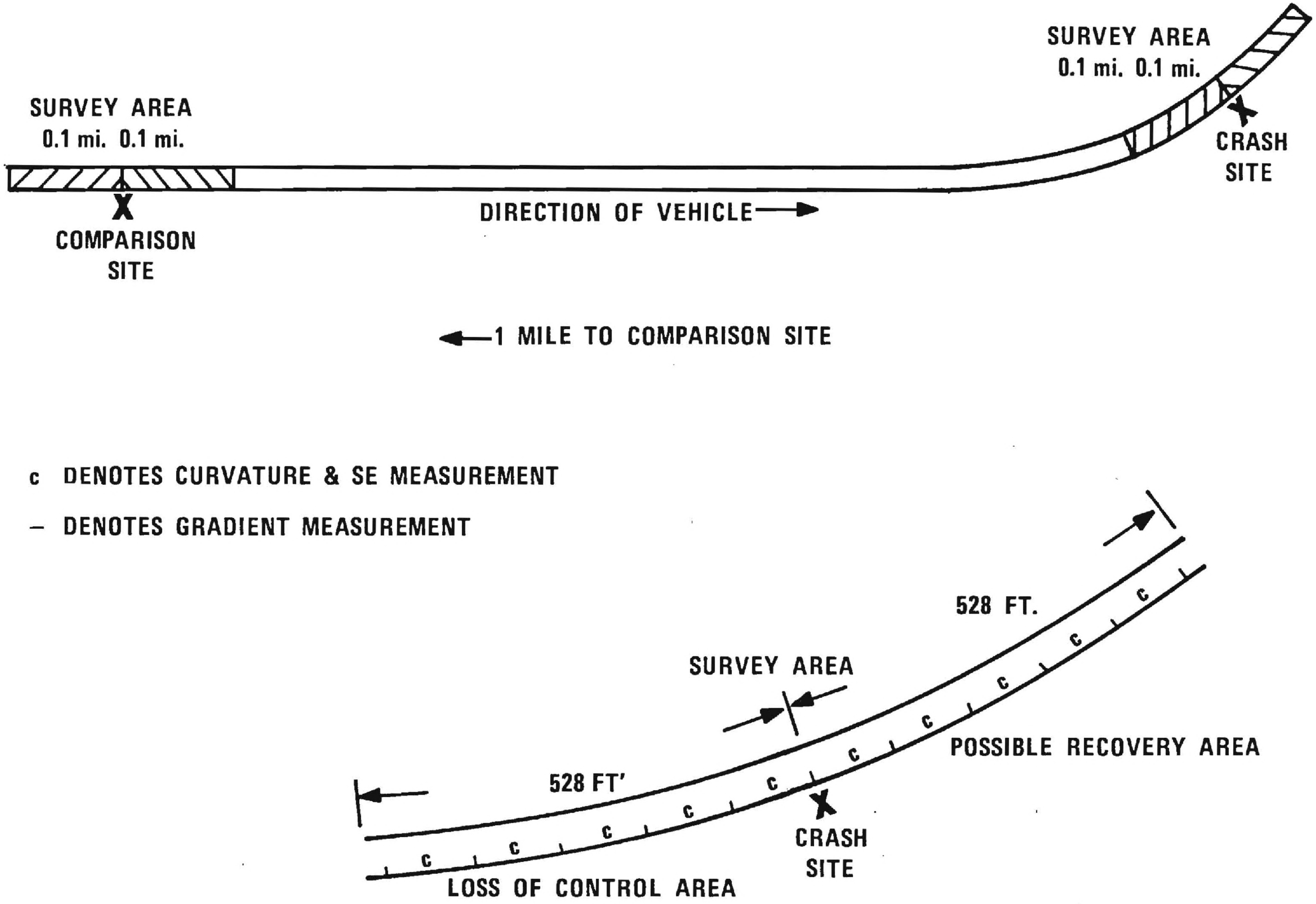

Figure 1. Hypothetical crash and comparison sites.

taken on the edge of the roadway. The middle ordinates were converted to degrees of curvature of the roadway. Superelevation and gradients were measured at the center of the side of the road that the driver had used when approaching the crash location. Those measurements were made with a specially designed instrument consisting of a four-foot carpenter's level with an adjusted calibrated leg. In the case of Interstate highways, curvature, superelevation and gradient data were taken from plan and profile sheets.

Inventories were taken of various types of fixed objects in 3-meter (10-foot) segments of a 9.1 meter (30-foot) border 160.9 meters (0.1 miles) in each direction from the crash and comparison sites respectively along the same side of the road on which the vehicle crashed. In addition, type of road, number of lanes and widths of pavement and shoulder were recorded.

Crash sites were located on functional classification maps that were obtained from the Office of Planning, Georgia Department of Transportation. The percentage distribution of functional classes of roadways at the crash sites was compared with the total mileages by functional class for the complete 163,131 kilometer (101,339 mile) system. This comparison provided a basis for determining the classes of roadways having the greatest need for hazard modification.

RESULTS

Twenty-seven of the 300 cases (9.0 percent) involved vehicles which crashed just beyond an intersection area. (Only six of the comparison sites had an intersection in the upstream area.) In 20 of these crashes, the driver was attempting to negotiate a turn at the intersection; in 7 crashes, the driver reportedly failed to stop at a STOP signed T-intersection. Because of the difficulties in measuring curvature for these cases, they were excluded from the analyses of the effects of curvature.

For the remaining 273 cases, 84 percent of the crash locations had curvature within 152 meters (500 feet) of the crash site compared with 72 percent of the comparison sites (Figure 2). More than 60 percent of the crash locations had road curvature greater than 6 degrees within 152 meters (500 feet) of the crash sites, but less than 38 percent of the comparison locations had curvature greater than 6 degrees within 152 meters of the sites. The difference in distribution of curvature between the crash and comparison locations would not occur commonly from chance fluctuations in sampling. ($\chi^2 = 29.5$, df = 7, $p < 0.001$).

Remarkably, 133 (48.7 percent) of the crash sites had a maximum curvature greater than 9 degrees in the 152 meter (500 foot) section upstream of the crash site, while only 74 (27.1 percent) of the comparison sites had a maximum curvature greater than 9 degrees in the upstream section.

Figure 3 illustrates the percentage of road curvature greater than 6 degrees at intervals upstream and downstream from the crash and comparison sites. The largest differences occur in the area from 107 meters (350 feet) upstream to 15 meters (50 feet) downstream of the sites. The maximum curvature tended to occur at a point located 15 meters (50 feet) to 46 meters (150 feet) upstream of the crash site, as Figure 4 illustrates.

More than 66 percent of the vehicles crashing on or near curves (Types 3, 4, 5, 6, Figure 5) left the outside of the curve (Types 3 and 5), and such events accounted for approximately half of the crashes overall.

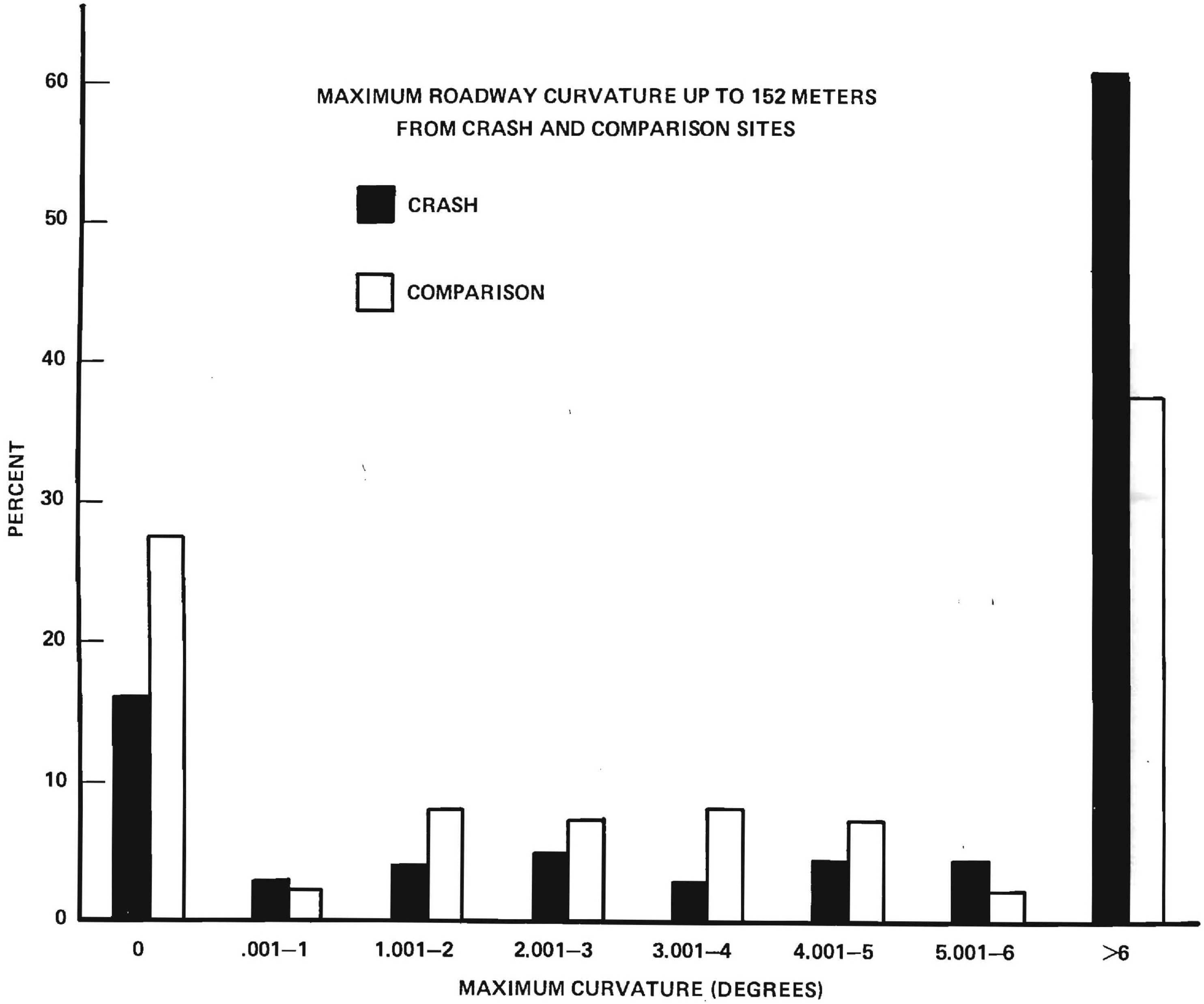

Figure 2. Maximum roadway curvature up to 150 meters (0.1 mile) from crash and comparison sites.

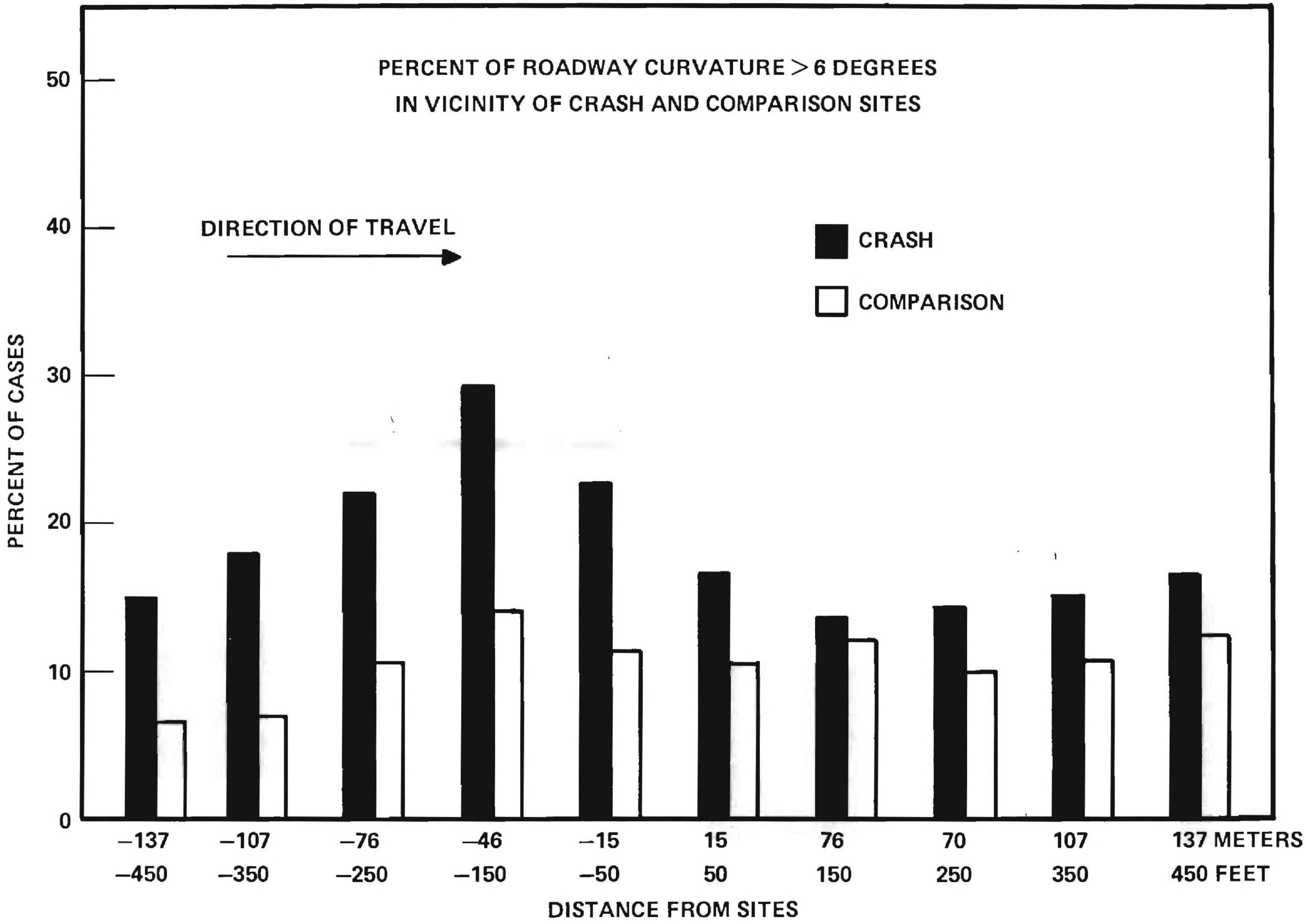

Figure 3. Percent of roadway curvature greater than 6 degrees in the vicinity of crash and comparison sites.

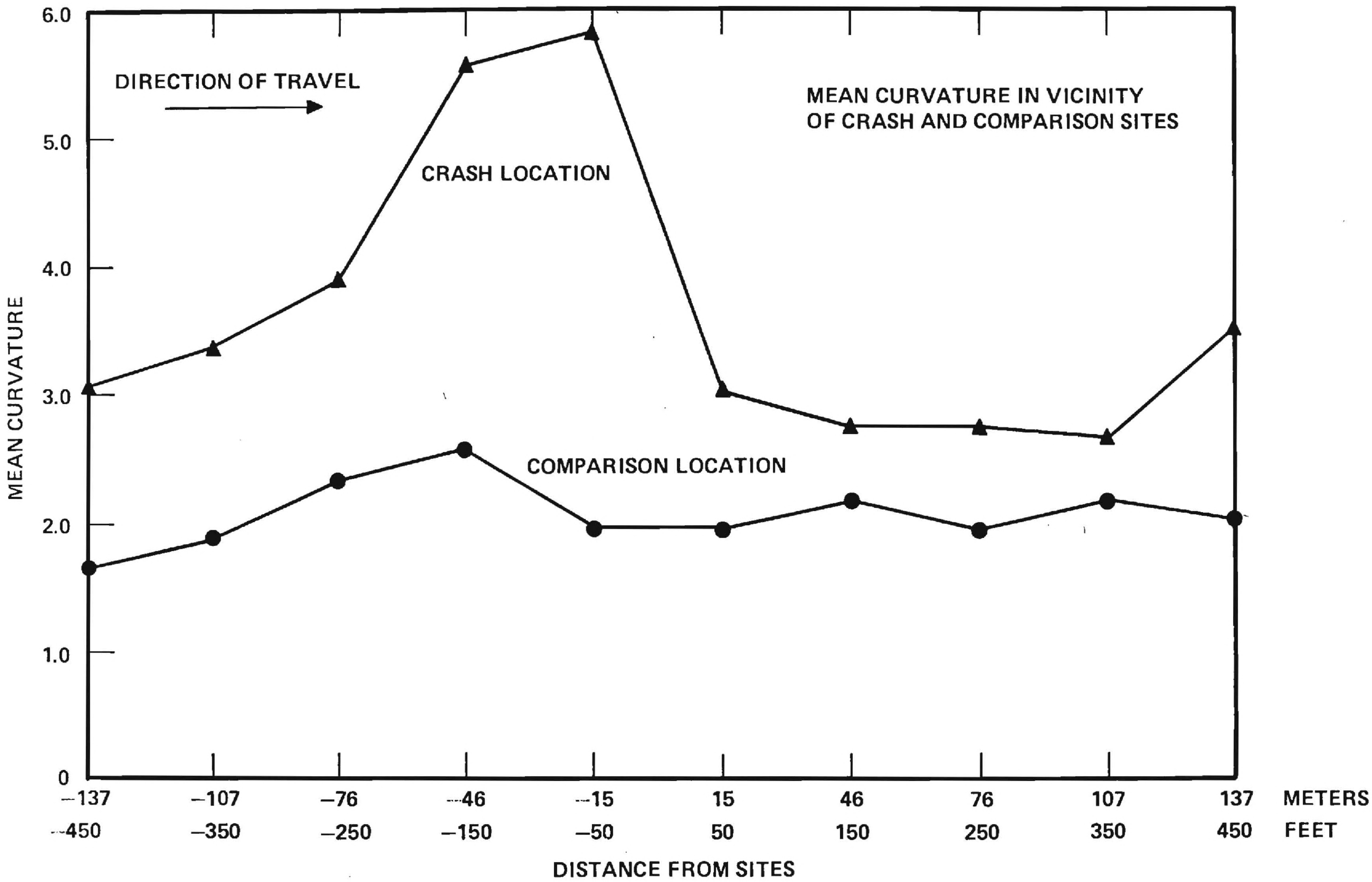

Figure 4. Mean curvatures observed at various section positions.

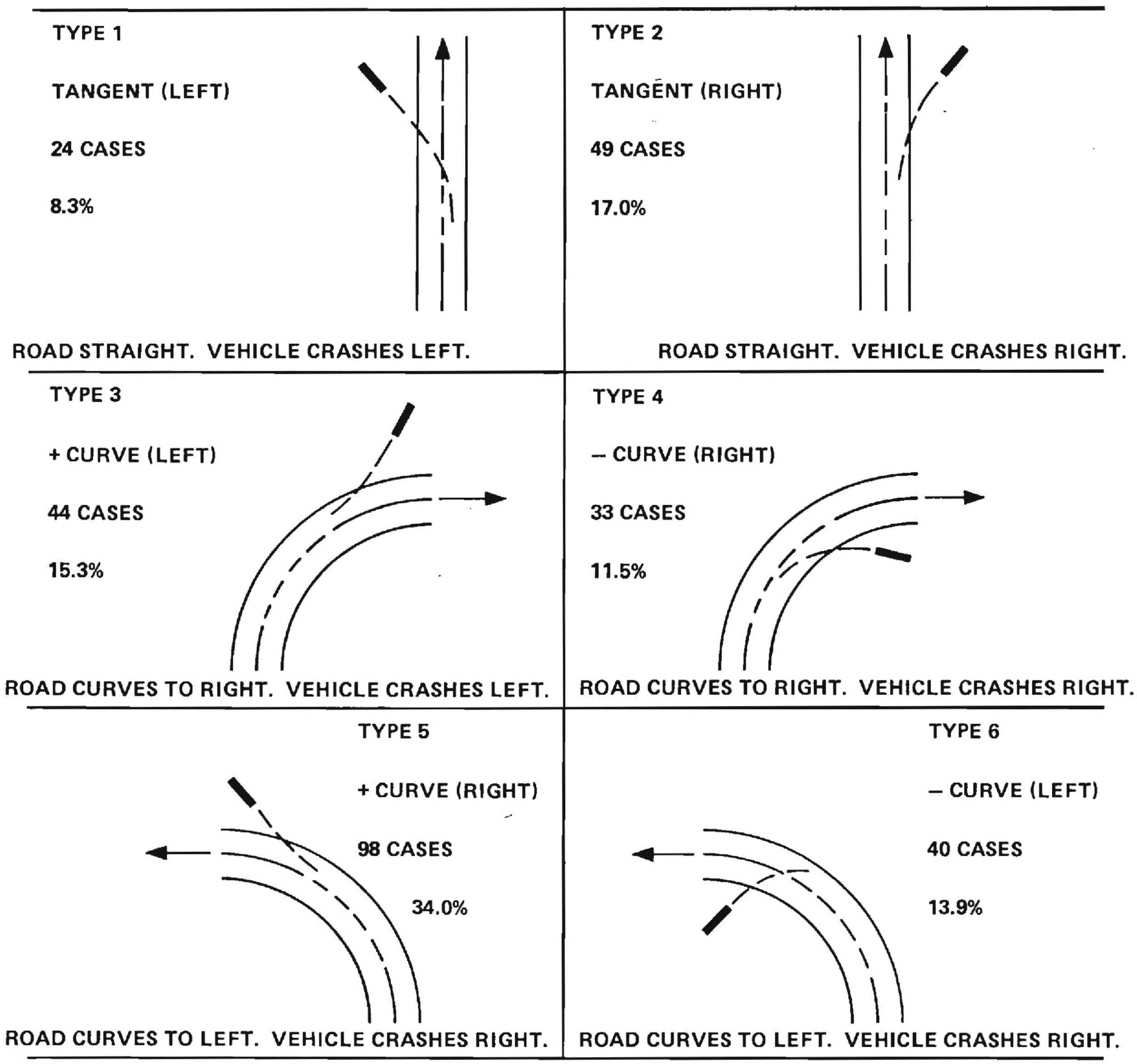

Figure 5. Percent of crashes into roadside objects by type of curvature.

The results for superelevation (not shown) closely parallel those for curvature. Analyses failed to show a major problem of horizontal curves with inadequate or adverse superelevation.

Downhill gradient was found more often characteristic of roadways on which the vehicles approached the crash sites than of roadways on which the vehicles approached the comparison sites. Figure 6 presents the average road gradients at 30 meter (100 foot) intervals within 152 meters (500 feet) of the fatal crash and comparison sites. The figure shows a greater tendency for negative gradients to occur in the area upstream from the crash site. Positive gradients were observed more commonly beyond the crash sites suggesting that the crash sites were often near the points where downhill gradient ended and uphill gradient began. An analysis of variance indicated that the differences in gradient between the crash and comparison sites were significant at the four stations 122 meters (400 feet) upstream of the sites ($p < 0.10$).

Extremes in downhill gradient alone did not discriminate crash and comparison sites substantially more than moderate downhill gradient. Figure 7 presents the minimum gradient observed within 152 meters (500 feet) in the approaches to the crash and comparison sites. Minimum gradient of minus three percent or less was more frequent in approaches to the crash locations while greater than minus three percent gradient was more frequent in approaches to the comparison sites.

Consideration of maximum road curvature and minimum gradient simultaneously resulted in substantial discrimination of crash and comparison locations. Table 3 presents percent of crash and comparison sites for combinations of maximum curvature and minimum gradient. Only 10 percent of comparison loca-

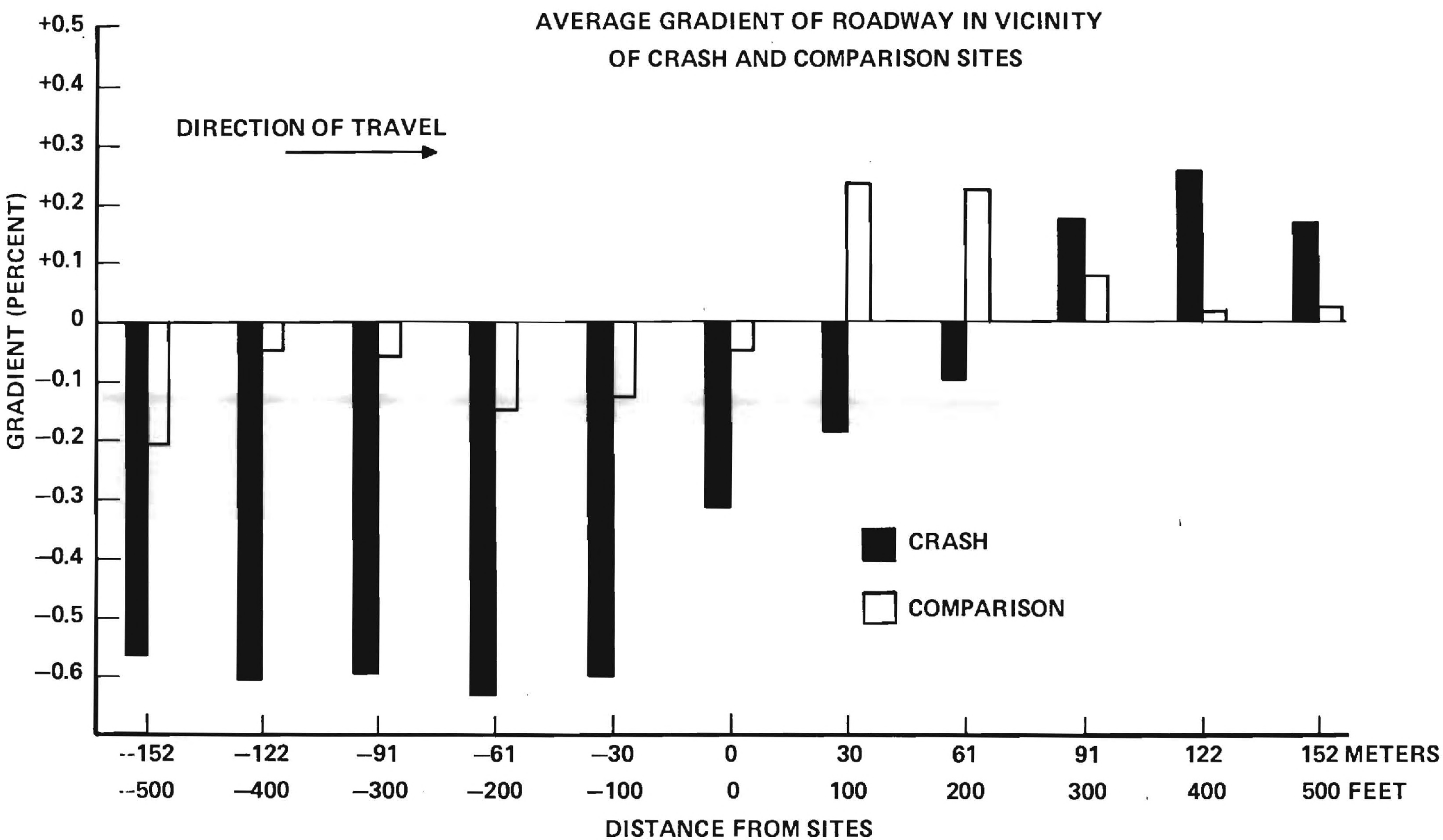

Figure 6. Average gradient of roadway in vicinity of crash and comparison sites.

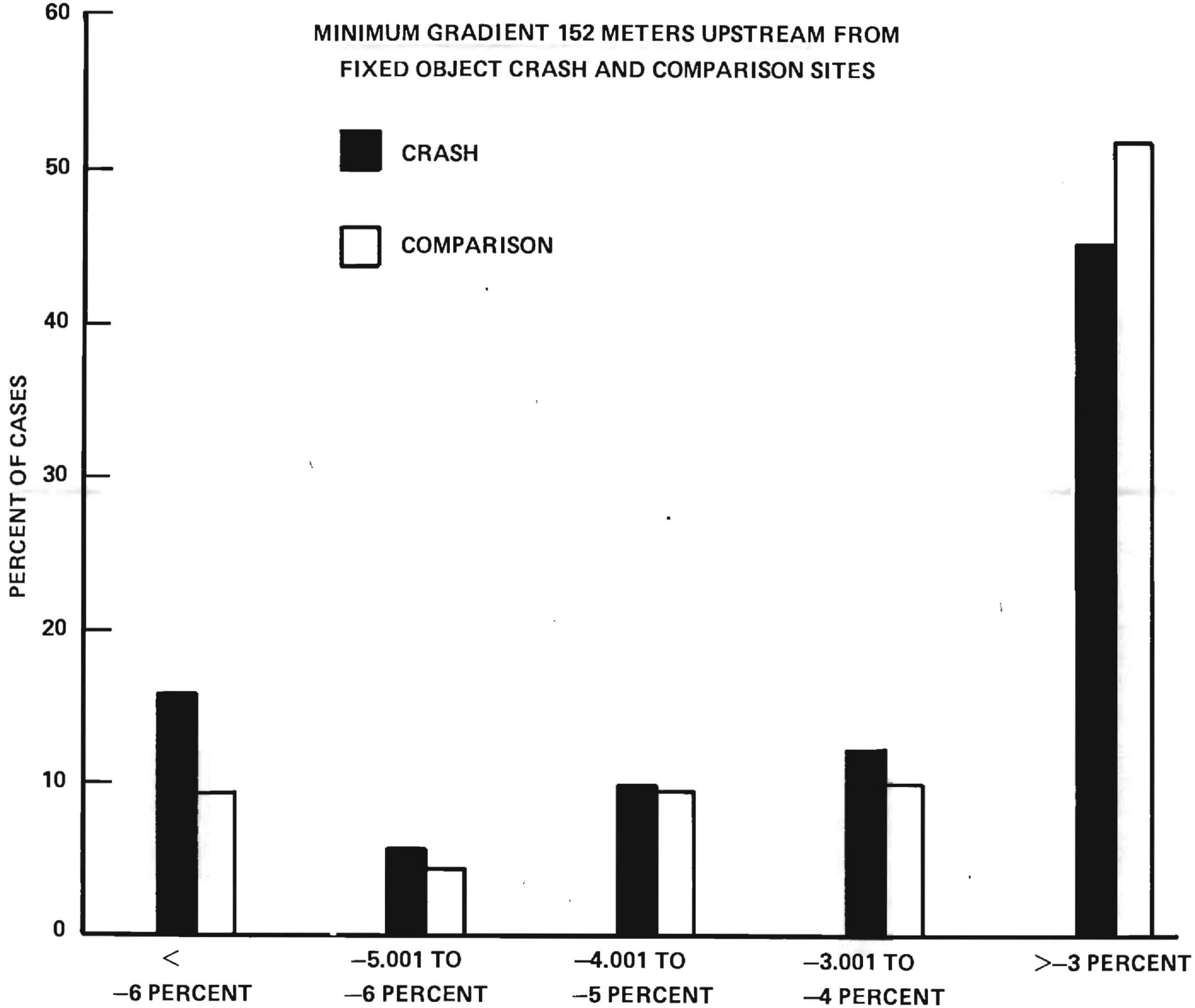

Figure 7. Minimum gradient observed upstream from crash and comparison sites.

Table 3. Percent of Crash and Comparison Sites for Combinations of Maximum Curvature and Minimum Gradient.

		Percent of Sites with Combinations of Max. Curvature & Min. Gradient Shown	
Maximum Curvature	Minimum Gradient	Crash Sites	Comparison Sites
>9°	<-3%	24.2	10.3
>9°	≥-3%	24.5	16.8
6.01° - 9.00°	<-3%	4.8	3.7
6.01° - 9.00°	≥-3%	7.0	6.6
3.01° - 6.00°	<-3%	5.1	5.1
3.01° - 6.00°	≥-3%	6.6	12.5
0 - 3.00°	<-3%	9.1	13.9
0 - 3.00°	≥-3%	18.7	31.1
		100.0	100.0

tions had maximum curvature greater than 9 degrees combined with minimum gradient of minus 3 percent or less while 24 percent of fixed object crash sites had such a combination of curvature and gradient.

The roadways at the crash sites had significantly narrower pavements ($p = 0.05$) and shoulders ($p = 0.10$) than those at the comparison sites, but differences in the number of driveways and intersections were not significant ($p > 0.9$, 0.7, respectively). See Table 4.

For each crash location, the roadways were classified functionally using classifications employed by the State Department of Transportation. Table 5 shows the percent of crash locations of four general classes of road compared to percent of all Georgia roads in each class. The comparison suggests a need to concentrate modification efforts first on nonlocal roads, especially arterial streets and highways. Thirty-seven percent of the crashes occurred on arterials which comprise only 13 percent of the roadways in the state.

Table 6 presents the average numbers or length of potential hazards within 9 meters (30 feet) of the roadway 161 meters (0.1 mile) upstream from the crash and comparison sites. Similar data for the downstream section are given in Table 7. The data reveal that the density of potential hazards differed little between crash locations and the comparison locations. This implies that fixed object crash sites are not just a result of there being more objects to hit at these locations than elsewhere, such as at comparison sites.

On average, the crash sites had about 26 narrow potential hazards and 194 meters (636 feet) of elongated potential hazards within 9 meters (30 feet) of the roadway per 161 meters (0.1 miles) adjacent to the crash sites. An average of 29 narrow objects and 181 meters (594 feet) of elongated potential hazards were in a like area adjacent to comparison sites.

Table 4. Mean Values for Roadway Features at Crash and Comparison Sites

	Crash Site	Comparison Site
Pavement width	31.4	34.2
Shoulder width	3.8*	4.5*
Intersections/0.2 mile	0.91	0.89
Driveways/0.2 mile	3.2	3.1

* Roadways with curb and gutter sections were assigned zero shoulder width.

Table 5. Comparison of Functional Class of Roadway at Crash Sites with that of all Georgia Roads.

Roadway Class	Percent occurring in Roadway Class Shown: Crash Sites	Georgia Roads
Principal arterial	14.3	5.3
Minor arterial	22.3	7.7
Collector	23.3	23.2
Local	40.0	63.8

Table 6. Average Number of Narrow Potential Hazards and Meters+ of Elongated Potential Hazards at Crash and Comparison Sites 9 Meters off the Pavement and 161 Meters in the Direction from which the Vehicle Traveled (Upstream).

	Crash Sites				Comparison Sites			
Meters from Pavement	0-3	3-6	6-9	Total	0-3	3-6	6-9	Total
Narrow Potential Hazard (Number)								
Trees	1.5	6.8	8.4	16.7	1.3	7.2	8.7	17.2
Utility Poles	1.0	0.6	0.2	1.8	1.0	0.6	0.2	1.8
Traffic/Signal Posts	1.1	0.4	0.1	1.6	1.1	0.4	0.2	1.7
Street Luminary Poles	0.2	*	*	0.2	0.1	0.1	0.2	0.4
Other Narrow Objects	1.9	1.7	1.1	4.7	1.7	2.1	1.3	5.1
Total	5.7	9.5	9.8	25.0	5.2	10.4	10.6	26.2
Elongated Potential Hazards (in Meters)								
Guard Rail	7.2	5.3	1.3	13.8	7.3	4.6	2.7	14.6
Curbs	33.5	3.9	0.3	37.7	32.3	3.6	1.7	37.6
Embankments	15.4	10.3	2.5	28.2	14.8	14.2	3.4	32.4
Banks-Cuts	12.9	15.9	5.8	34.6	11.0	13.9	6.3	31.2
Ditches	26.9	13.4	2.0	43.2	23.5	14.4	2.1	40.0
Median Barriers	1.6	1.8	0.0	3.4	0.5	2.3	0.2	3.0
Other	6.7	15.5	6.2	28.4	4.8	7.3	7.1	19.2
Total	104.2	66.1	18.1	189.4	94.2	60.3	23.5	178.0

+ 1 meter = 3.28 feet

* <0.05 but not 0.00

Table 7. Average Number of Narrow Potential Hazards and Meters+ of Elongated Potential Hazards at Crash and Comparison Sites 9 Meters off the Pavement and 161 Meters Beyond the Sites in the Direction the Vehicle was Traveling (Downstream).

	Crash Sites				Comparison Sites			
Meters from Pavement	0-3	3-6	6-9	Total	0-3	3-6	6-9	Total
Narrow Potential Hazards (Number)								
Trees	1.6	7.1	10.2	18.9	1.0	9.4	13.4	23.8
Utility Poles	1.0	0.6	0.2	1.8	0.9	0.5	0.3	1.7
Traffic Sign/Signal Posts	0.9	0.3	0.1	1.3	1.0	0.4	0.1	1.5
Street Light Poles	0.1	0.1	*	0.2	0.2	0.1	0.1	0.4
Other Narrow Objects	2.3	1.4	0.7	4.4	2.1	1.6	1.1	4.8
Total	5.9	9.5	11.2	26.6	5.2	12.0	15.0	32.2
Elongated Potential Hazards (In Meters)								
Guardrails	5.7	4.6	1.4	11.7	7.5	5.5	1.2	14.2
Curbs	36.1	2.7	0.7	39.5	37.0	2.2	0.8	40.0
Embankments	14.1	12.3	3.2	29.6	14.2	12.6	4.7	31.5
Banks-Cuts	13.4	15.6	3.6	32.6	10.0	16.2	8.5	34.7
Ditches	26.7	10.6	2.3	39.6	19.0	16.9	4.5	40.4
Median Barriers	1.3	2.1	0.1	3.5	0.5	2.8	0.4	3.7
Other	15.7	19.2	7.5	42.4	9.8	5.8	3.8	19.4
Total	113.0	67.1	18.8	198.9	98.0	62.0	23.9	183.9

+ 1 meter = 3.28 feet
* <0.05 but not 0.00

About 90 percent of the objects apparently taking the brunt of the impacts were within 9.1 meters (30 feet) from the pavement edge (Figure 8) and 97 percent were within 15.2 meters (50 feet). The objects struck and the percentage of crashes involving them are: utility poles -- 24 percent; trees -- 16 percent; ditches and banks -- 13 percent; guardrail -- 11 percent; bridges -- 6 percent; fences -- 6 percent; signs -- 4 percent; other -- 20 percent (including culverts, mail boxes, fire hydrants, walls, curbs, parked vehicles, boulders, posts, street light poles, barriers, and barricades).

Table 8 presents the average number of objects in a path 5 meters (15 feet) to each side and 27 meters (90 feet) beyond the crash site in the direction the vehicle travelled. On average, seven narrow potential hazards were found in this area.

SUMMARY AND CONCLUSIONS

Engineering surveys have been performed at 600 locations where fixed object crashes occurred and at 600 comparison locations. Three hundred pairs of these surveys were performed in 1974-75 for fatal crashes, and conclusions based on the results of that study were presented in earlier reports (2,3). In that study, virtually all of the locations of fatal collisions into roadside objects that occurred in 108 contiguous counties in North and Central Georgia during a 14-month period were surveyed.

This study focused on the locations of 300 additional fixed object crashes, selected from a population of property damage only, non-fatal injury, and fatal crashes that occurred in three Georgia counties during a five month period in 1977-78. The results of this latter study generally validate the findings of the earlier one. The conclusions listed below are based on the combined results of both studies, comprising 600 paired surveys.

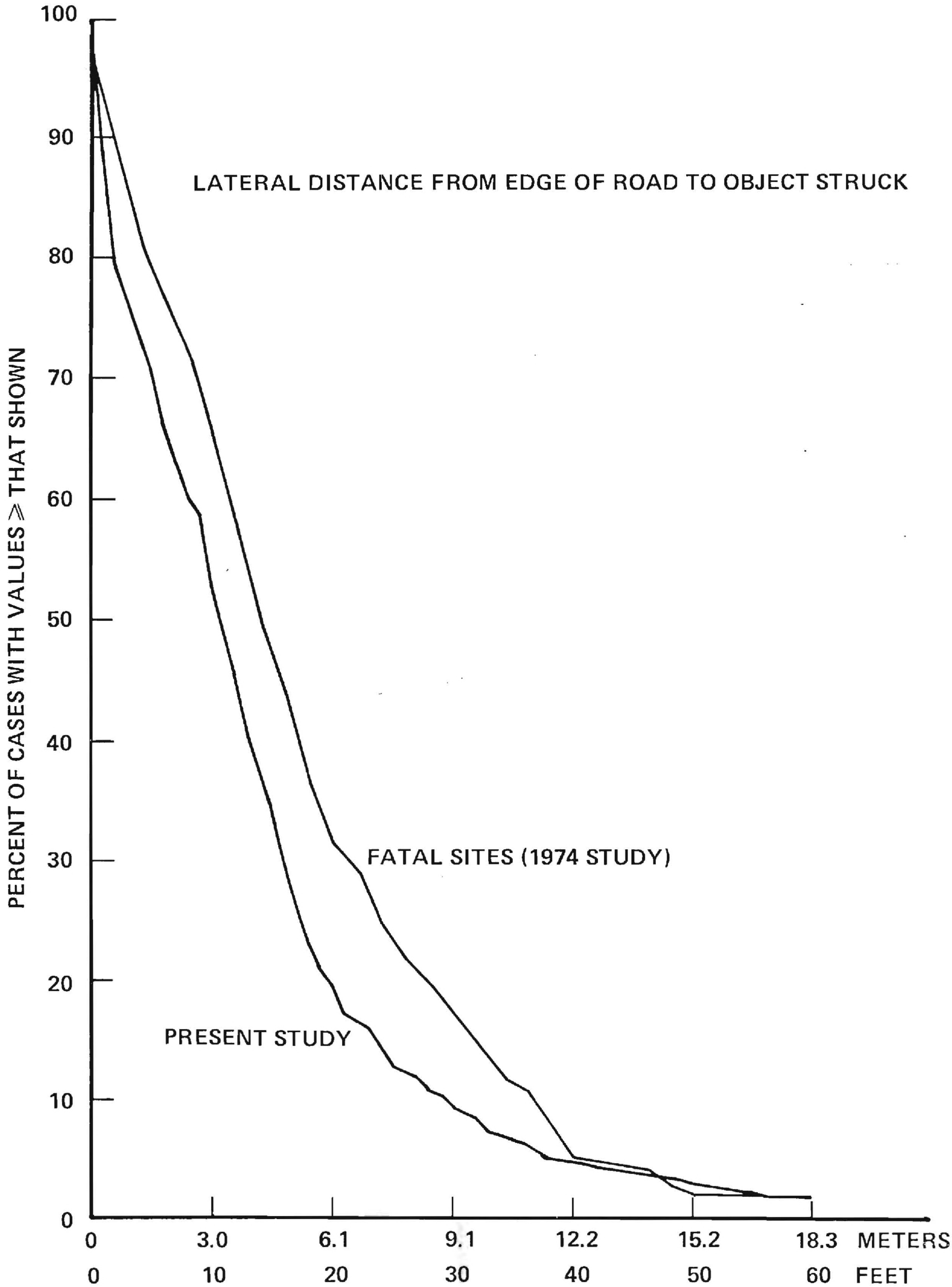

Figure 8. Distribution of lateral distances from edge of road to object struck.

Table 8. Average Number of Objects 4.6 Meters+ to Each Side and 27 Meters Beyond the Crash Site in the Direction of the Fatal Vehicles' Movements.

	Vehicle Path Beyond the Fatal Site (Meters) 0-9	9-18	18-27	Total
Narrow Potential Hazards (Number)				
Trees	1.9	2.1	2.3	6.3
Utility Poles	0.1	*	*	0.1
Traffic Sign/Signal Poles	0.1	*	*	0.1
Street Luminary Poles	*	0.0	*	*
Other	0.4	0.2	0.2	0.8
Total	2.5	2.3	2.5	7.3
Elongated Potential Hazards (Meters)				
Guardrails	0.5	0.2	0.2	0.9
Curbs	0.7	0.4	0.5	1.6
Embankments	1.0	0.7	0.6	2.3
Banks-Cuts	1.1	0.8	0.7	2.6
Ditches	0.9	0.5	0.4	1.8
Median Barriers	*	0.1	*	0.1
Other	1.6	1.5	1.1	4.2
Total	5.8	4.2	3.5	13.5

+ 1 meter = 3.28 ft.
* <0.05 but not 0.0

1. Fixed object crashes are more likely to occur:

   a. Along arterial and collector roads than along local roads

   b. Along the right side of roadways than along the left side from the driver's perspective

   c. Along curved sections than along straight sections

   d. Along the outside of curves than along the inside

   e. In the area downstream from a curve than in the area upstream

   f. Along roadways with negative gradient than with positive gradient

   g. Along roadways with narrow pavements and shoulders than roadways with wide pavements and shoulders

2. Approximately 90 percent of fixed object crashes result from collisions with objects within 30 feet of the pavement edge.

3. For the general population of fixed object accidents, the crash locations are best discriminated from comparison locations by a combination of curvature greater than 9 degrees and downhill gradient steeper than 3 percent.

4. For the fatal fixed-object crash population, the crash locations are best discriminated from comparison locations by a combination of curvature greater than 6 degrees and downhill gradient steeper than 2 percent.

ASSESSMENT AND RECOMMENDATIONS

Since the early 1960's highway engineers have become increasingly aware of the fixed object hazards that border U. S. highways, and a large number of remedial programs have been established. The Highway Safety Act of 1973 provided categorical funding for several specific programs designed to reduce the number and severity of highway crashes including a program for the elimination of roadside obstacles. The law, which provided 90 percent Federal Funding, has been the impetus for a variety of roadside improvement activities.

The 1976 Highway Safety Act combined the Elimination of Roadside Obstacle program with the High Hazard Locations program. The law now requires each state to maintain a survey of all hazardous roadside obstacles, to assign priorities for the correction of such obstacles, and to schedule projects for their elimination. States are further required to maintain a survey of high hazard locations (normally based on police accident records) and carry out a priority schedule for remedial projects at high hazard locations.

As a result of Federal support programs, state highway agencies have become more involved in roadside improvement activities. By the end of the fiscal year 1977, more than $154 million had been obligated by the Federal Highway Administration for 1583 roadside safety projects (1). Although beneficial, such projects hardly represent a solution to the roadside hazard problem.

Field surveys have indicated that there are hundreds of millions of roadside obstacles bordering the nation's highways. The modification or removal of all of these hazards would require many years and would cost tens of billions of dollars. The problem that remains is manifestly too large for treatment by inventory and analysis of individual obstacles. Roadside improvement programs are needed covering extensive segments of highway with focus on those areas most likely to experience encroachment by errant vehicles. Clearly, selective removal or modification based on some rational priority improvement scheme is needed.

The combined results of this and the earlier study suggest a clear set of priorities for removing roadside hazards or modifying them or the roadway to manage the energy of errant vehicles to protect the vehicle occupants. Though slightly more conservative than one dictated solely by the results of this study, the priority improvement scheme recommended in the earlier study of fatal fixed object crashes is entirely suitable to ameliorate the larger population of crashes.

As Figure 9 illustrates, road locations with curvature greater than 6 degrees and negative (downhill) gradient of two percent or steeper in or prior to curves should be modified first. That task completed, the remainder of road locations with curvature greater than six degrees should then be modified. Following these in priority are locations with more than three degrees curvature.

The most probable locations of fixed object crashes can be further narrowed by concentrating on arterial and collector roads. The recommended approach to roadside hazard amelioration is to identify the types of roads in a given state that have a history of higher than average rates of fixed object crashes and to apply the noted curvature and gradient criteria to identify the most likely sites along those roads. Although the number and types of hazards on a particular road in a particular area may differ because of climate, land use and other factors, the association of curves and gradient with high risk locations is undoubtedly similar in all areas.

Since 66 percent of the crashes that occurred on or near curves were on the outside of the curves, that side of the road should take precedence in ameliorative efforts when resources do not allow such efforts on both sides of the road at every available site. Eventually both sides of the road must be modified for maximum benefit.

Finally, ameliorative efforts should be focused on fixed obstacles nearest the pavement edge, those in the vicinity of intersections, and those on the

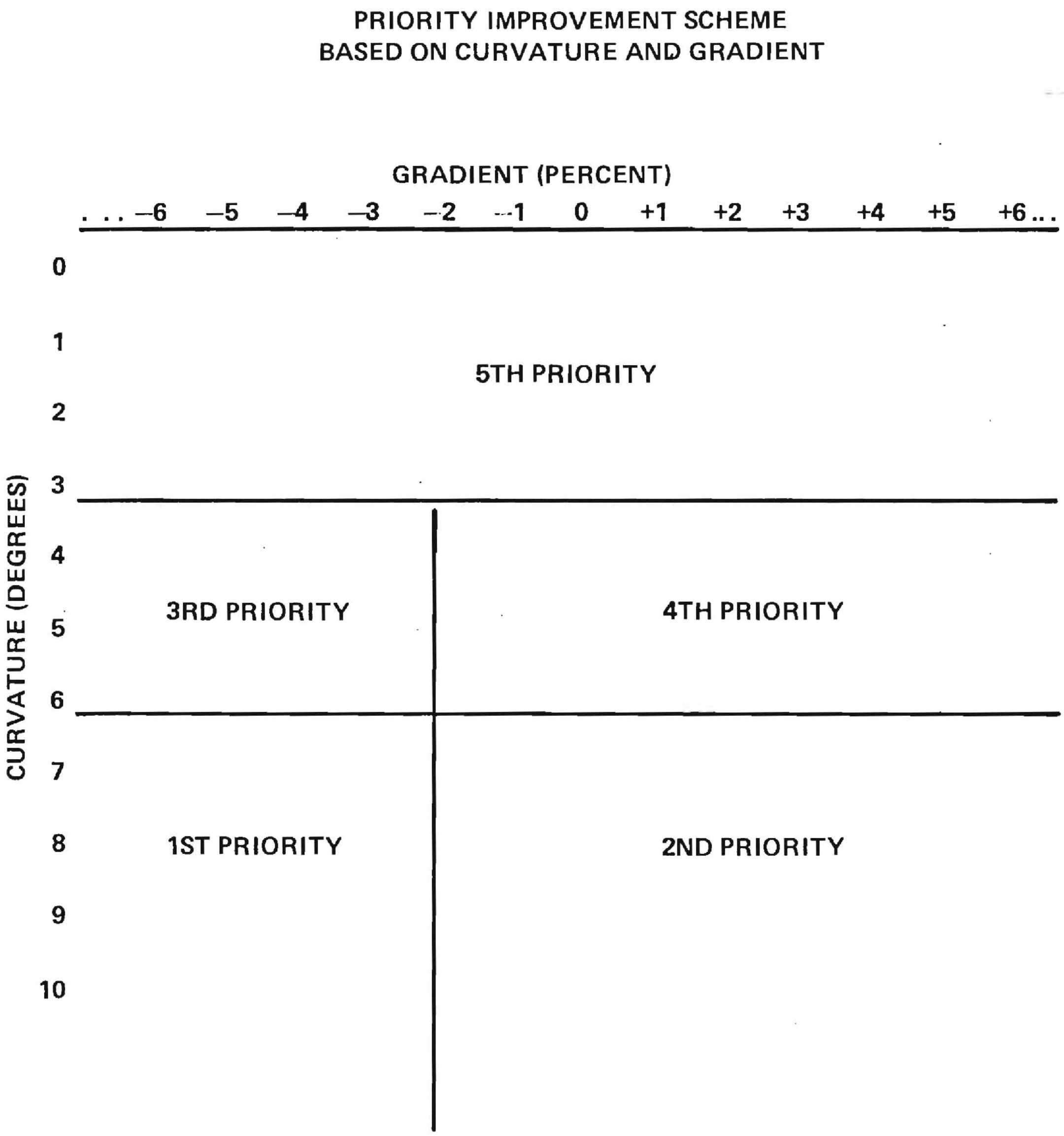

Figure 9. Priority improvement scheme based on curvature and gradient.

right side and in downstream sections of curves on one-way facilities.

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